Decadal Survey Tier 2 Mission Study
Summative Progress Report

ACE Radar

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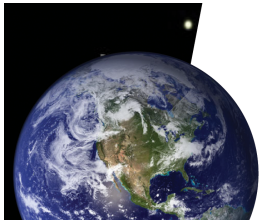
2010

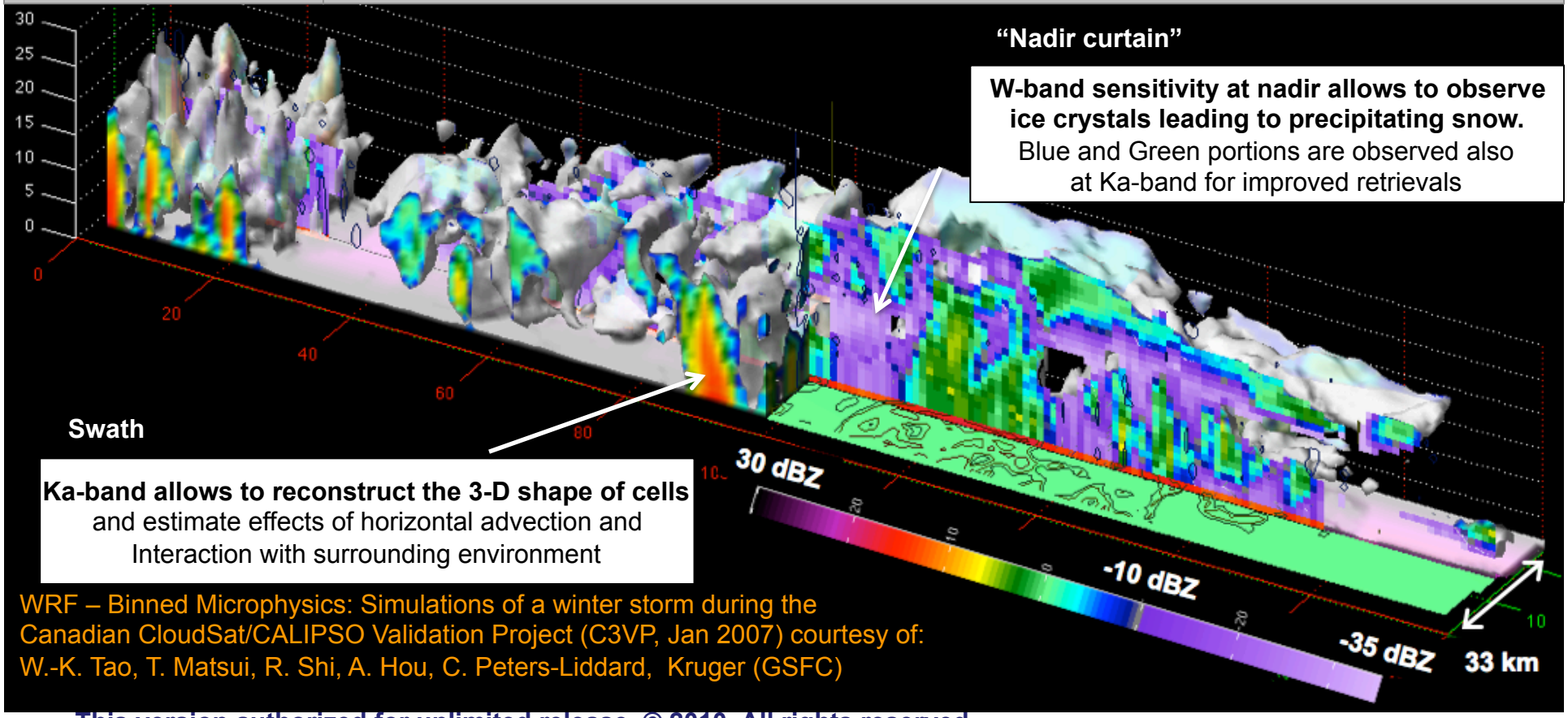


Instrument requirements

- Iterations with the Cloud Studies Team to converge on:
  - *Science **requirements** achievable with technology mature enough for low-risk implementation and launch within the decade*
  - *Science **goals**, prioritized in order of projected scientific impact, and potentially achievable with new technologies not mature yet, but potentially within the decade.*
- Result of the iterations:
  - *Confirmed DS choice of operating frequencies (Ka- and W- band) as most effective in cost/performance.*
  - *Measurement concepts are based on existing ground-based and airborne cloud and precipitation radars*
  - *Desired capabilities vs. current technology: challenging trade-offs*
    - Sensitivity vs. Scanning, Doppler vs. Scanning, Scanning vs. Polarization
    - Dual-goal approach adopted: one set for nadir curtain, one set for off-nadir
  - ***All requirements** plus a **subset of goals** is **achievable with current technology**.*
    - There are areas of **technological improvement** that are clearly **within reach** and could **increase the number of achievable goals** and/or **reduce mission risk/cost** .

The primary role of the radar is to profile clouds and precipitation.
The cloud science requirements map into the following instrument properties:

Instrument property	L2B		L2C	
Dual-Frequency	• Liquid water content	• Microphysics of the whole cloud-precipitation continuum	• Latent and Radiative Heating Rates	• Characterizing processes of precipitating clouds ..
Doppler	• Particle type & size • Process type • Convective Motion			• Convection-anvil mass fluxes …
Scanning (goal)	• Convective cell structure, statistics of broken cloud fields in 3D			… in 3D
Range resolution	Surface precipitation, microphysical processes in geometrically thin clouds			
Horiz. Resolution	Characterizing coupled dynamical and microphysical processes			



WRF – Binned Microphysics: Simulations of a winter storm during the Canadian CloudSat/CALIPSO Validation Project (C3VP, Jan 2007) courtesy of: W.-K. Tao, T. Matsui, R. Shi, A. Hou, C. Peters-Liddard, Kruger (GSFC)

Radar studies team: philosophy

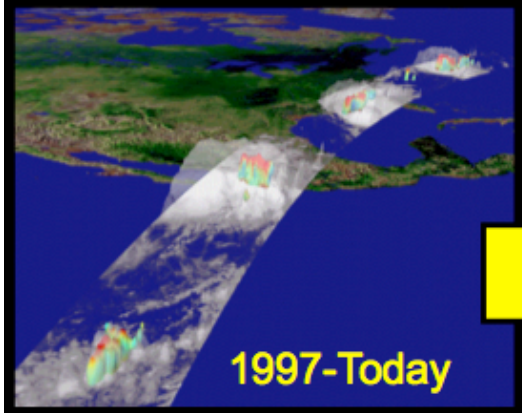
- **Develop a baseline radar concept capable of meeting requirements with mature technology**
  - *Maximize leverage of other missions and technology*

Mission	STATUS	HERITAGE/LEVERAGE
CloudSat CPR	Operational since 2006	Technology & algorithms
EarthCARE CPR	NET 2014	Technology & algorithms
GPM/DPR	NET 2013	Algorithms

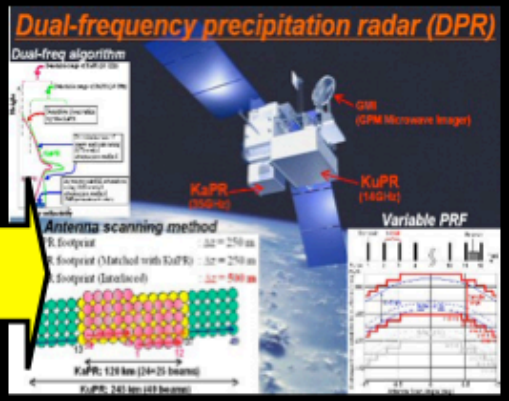
  - *Low risk implementation for a pre-2020 launch (i.e., 2018)*
  - *ACERAD (IIP'07, S. Durden, PI) instrument concept:*
    - meets all ACE requirements, but does not meet all the goals
    - provides a dataset vastly superior to its predecessors.
- **Identify technology areas:**
  - *to enable an improved instrument capable of addressing all SWG goals.*
  - *To reduce mission cost, risk, power consumption and data rate*

Cloud and Precipitation Radars in Space

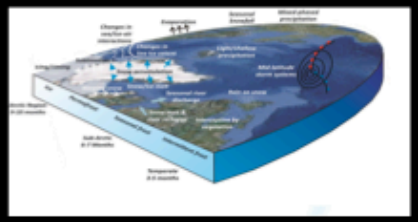
TRMM/PR – NICT/JAXA
Ku, Scanning , Tropical Rain



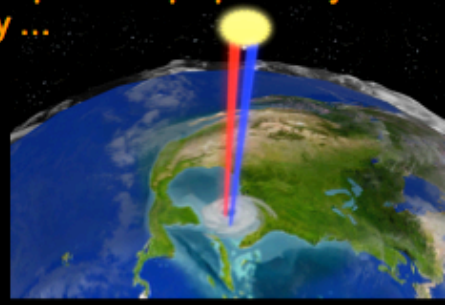
GPM/DPR – NICT/JAXA
Ku/Ka, Scanning, Precipitation



Some concepts under development or proposed by the international community …

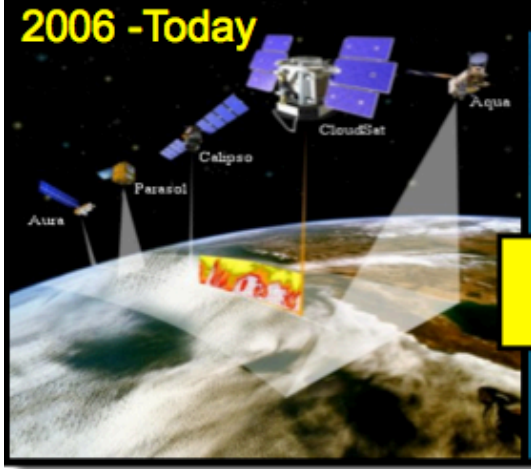


SnowSat / PPM
W/Ka, (Doppler)

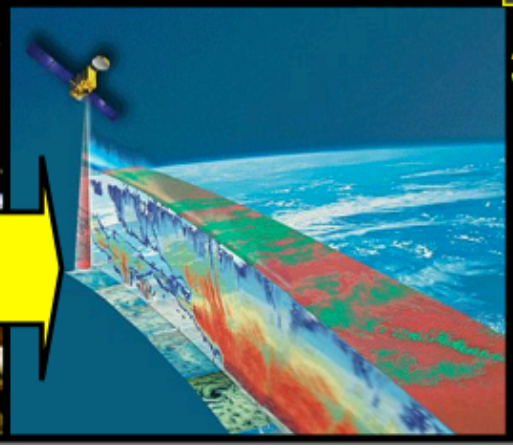


NIS
W/Ka, Scanning,
Doppler, GEO

CloudSat/CPR – JPL/NASA/CSA
W, -30dBZ , Clouds

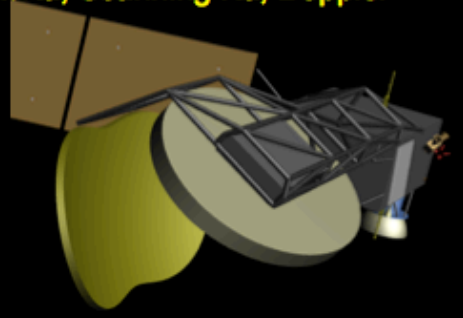


EarthCARE/CPR – NICT/JAXA
W, Doppler, Clouds

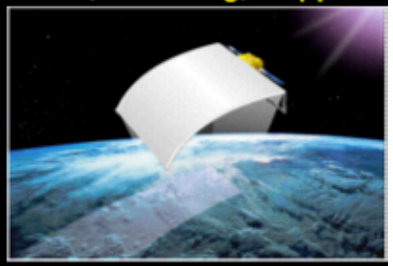


ACE Radar
W/Ka, Scanning, Doppler

ACE – ACERAD concept
W/Ka, Scanning Ka, Doppler

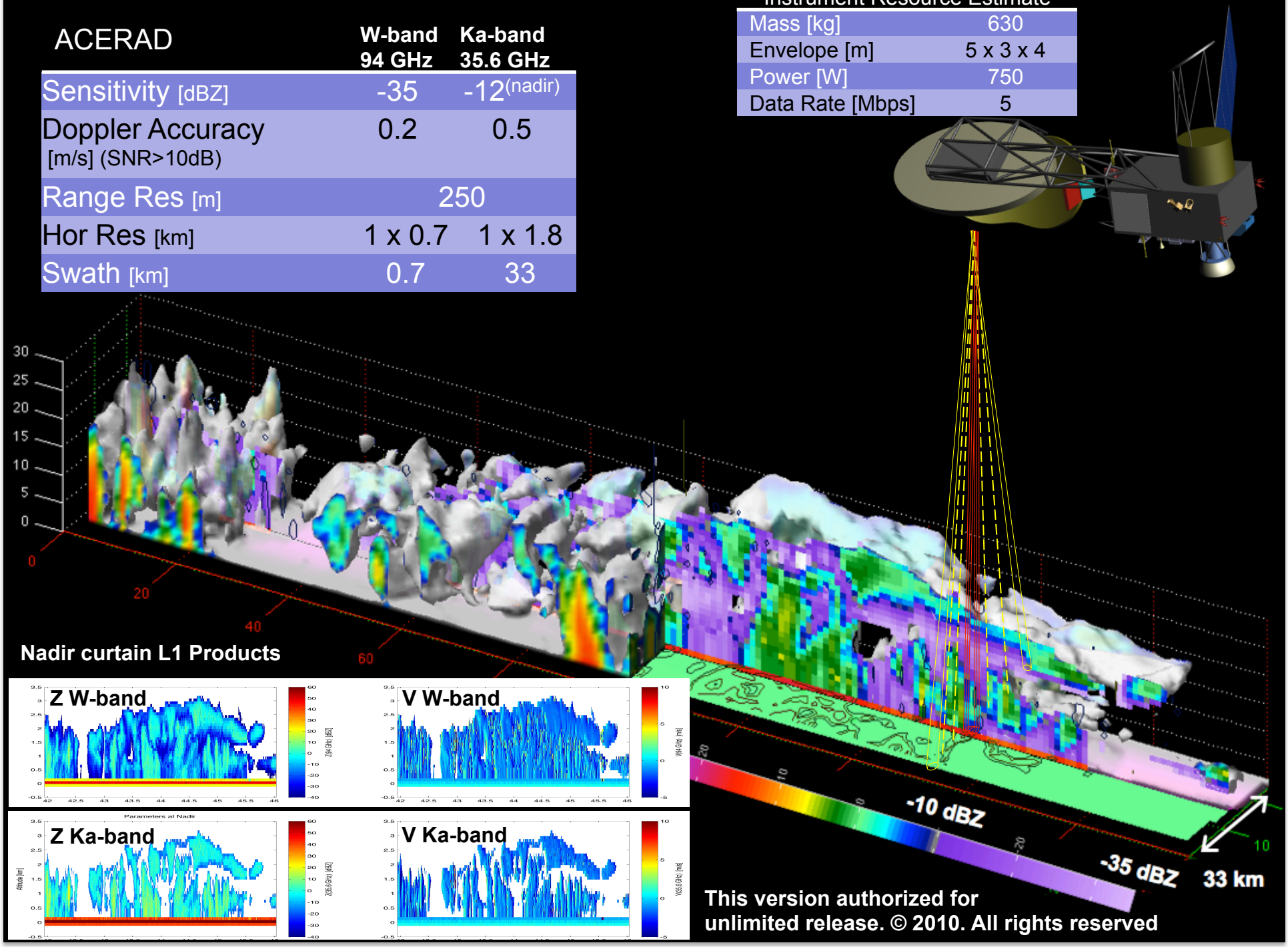


ACE –
Phased Array concepts
W/Ka, Scanning, Doppler



ACERAD	W-band 94 GHz	Ka-band 35.6 GHz
Sensitivity [dBZ]	-35	-12(nadir)
Doppler Accuracy [m/s] (SNR>10dB)	0.2	0.5
Range Res [m]	250	
Hor Res [km]	1 x 0.7	1 x 1.8
Swath [km]	0.7	33

Instrument Resource Estimate	
Mass [kg]	630
Envelope [m]	5 x 3 x 4
Power [W]	750
Data Rate [Mbps]	5



Nadir curtain L1 Products

Instrument requirements & goals

	PARAMETER	UNIT	REQUIREMENT	GOAL (#Priority)	ACERAD	Science Mnemonic
W-band, nadir	Min Det Sens	dBZ	-35	-40 (#3)	-35	EarthCARE level of detection.
	Doppler Acc	m/s	0.4	**0.2(#2)**	0.2	Precipitating/non-precipitating, sedimentation, cloud scale entrainment.
	Vert Res	m	250	**100 (#1)**	250	Melting layer, geometrically thin clouds, in-bin attenuation
	Sfc Cltr max hgt	m	500	**250 (#1)**	400	Cloud base vs surface precipitation.
	Hor Res	km	1 x 1	--	0.7 x 1	CRM scale.
	Polarimetry (LDR)		--	YES (#5)	YES	Mixed phase and multiple scattering.
W-band, off-nadir	Swath Width	km	--	≥2 (#4)	--	Convective cell resolution (10km), radiometer footprint (25km). Ka-radar footprint (2km)
	Min Det Sens	dBZ	--	-20	--	All light precipitation, most large particle clouds.
	Doppler Acc	m/s	--	1	--	
	Vert Res	m	--	250	--	
	Hor Res	km	--	1 x 1	--	
Ka-band, nadir	Min Det Sens	dBZ	-10	**-20 (#2)**	-12	Most (all) light precipitation, some (all) large particle clouds.
	Doppler Acc	m/s	1	0.5 (#3)	0.5	Rain/no rain, convection.
	Vert Res	m	250	100 (#4)	250	
	Sfc Cltr max hgt	m	500	250 (#4)	400	
	Hor Res	km	2 x 2	1 x 1	1.8 x 1	CRM scale / matched beam.
	Polarimetry (LDR)		--	YES (#5)	YES	
Ka-band, off-nadir	Swath Width		--	**>25 (#1)**	33	Convective cell resolution, radiometer footprint. 100km would achieve meso-scale features.
	Min Det Sens	dBZ	--	-10	-10	
	Doppler Acc	m/s	--	1	1	
	Vert Res	m	--	250	250	
	Hor Res	km	--	2 x 2	1.8 x 1	

Requirement not met
Requirement met
Goal met

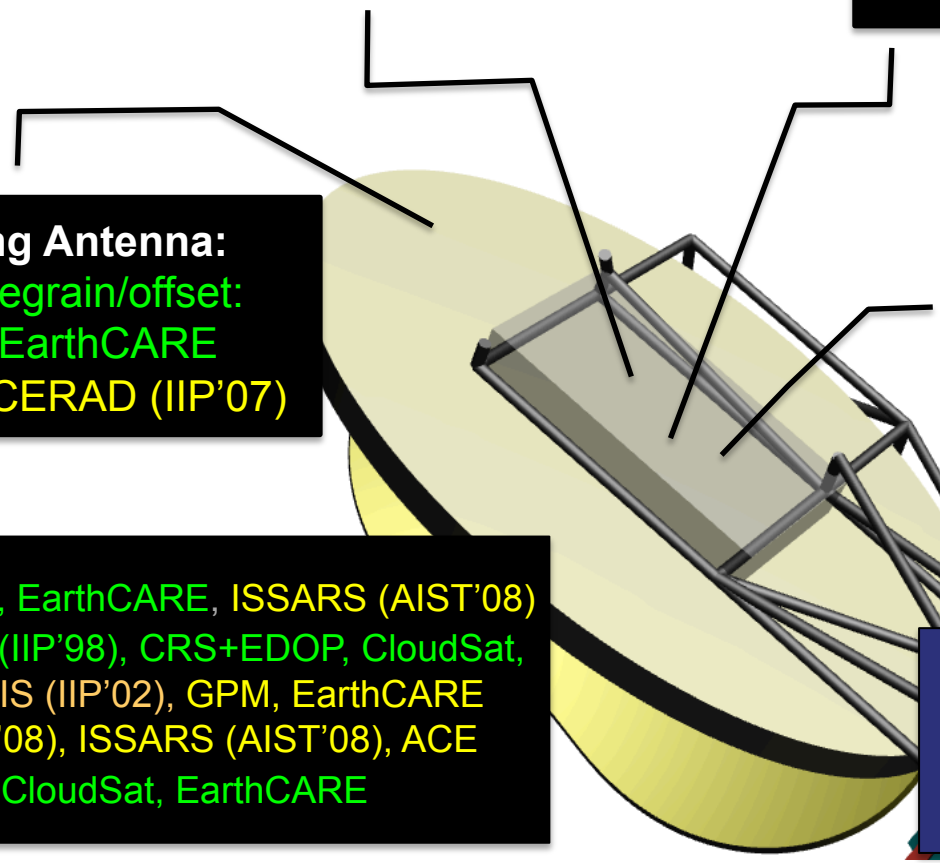
ACERAD heritage and technology investments

RF Transmission Line:
W-band single-pol QOTL: CloudSat, EarthCARE
Dual-Pol QOTL: ACERAD (IIP'07)
W-/Ka-band Frequency Selective Surface: ACERAD (IIP'07)
Ka-band T/R switches and wg: PR-2 (IIP'98, ATIP'99), GLISTIN (IIP'04)

High Power Amplifier:
CloudSat, EarthCARE, ACERAD (IIP'07),SWOT
Digital:
CloudSat, Onboard Processor-FPGA (AIST'99), Doppler-FPGA(AIST'02)

Rx chain
Receiver: CloudSat, EarthCARE, PR-2 (IIP'98), ACR, CRS, GPM, etc..

Collimating Antenna:
Open Cassegrain/offset:
CloudSat/EarthCARE
Dragonian: ACERAD (IIP'07)



System: CloudSat, EarthCARE, ISSARS (AIST'08)
Algorithm: PR-2 (IIP'98), CRS+EDOP, CloudSat, APRA (IIP'01), NIS (IIP'02), GPM, EarthCARE (SALMON/USPI'08), ISSARS (AIST'08), ACE
Cal/Val: CloudSat, EarthCARE

LEGEND
Current technology investment
Relevant heritage at TRL 6 or more
Direct technology heritage

ACERAD: IIP'07 Progress

- **Dual-Polarization W-band Quasi-Optical Transmission line**
  - *design completed, prototype implemented, testing in progress.*
  - *TRL 4, expected TRL 6 in 2011.*
- **W-/Ka-band Frequency Selective Surface**
  - *design completed, prototype implemented, testing in progress.*
  - *TRL 4, expected TRL 6 in 2011.*
- **High-efficiency Dragonian Antenna**
  - *design completed, prototype under implementation*
  - *TRL 3, expected TRL 5 in 2011.*

ACERAD: Payload configuration

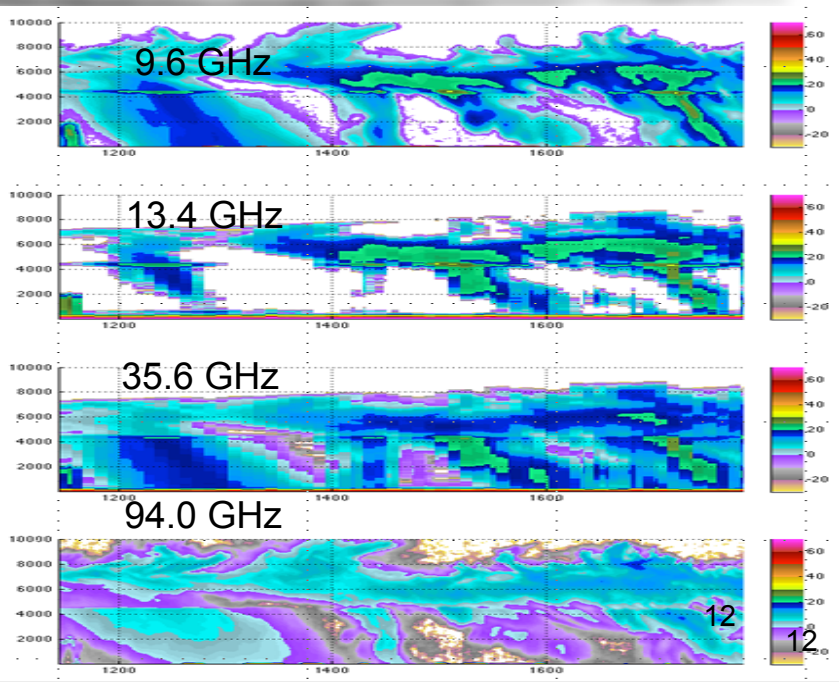
- The latest mission configuration studies show that ACERAD could be deployed in the selected launcher class **without deployable parts**.

Algorithm Development

- Radar algorithms development will benefit from **extensive heritage** from airborne and ground based radars and leverage on other missions.
  - *APR-2 (IIP'98), CRS+EDOP, HIWRAP (IIP'04)*
  - *GPM, EarthCARE, CloudSat*
  - *A-Train multi-instrument algorithms*
- However – the following tasks are necessary:
  - *Advanced forward models*
  - *Retrieval algorithms for a spaceborne W-/Ka- Doppler radar*
  - *Quantitative assessment of advantages and potential of alternative technological or algorithmic solutions*
  - *Multi-instrument algorithms*

Airborne simulators supporting cal/val

- Large datasets of X-/W-band and Ku-/Ka-band airborne Doppler radar data exist
- Very small datasets of colocated W-/Ka-measurements exist:
  - *Wakasa Bay Experiment 2003, APR-2 (Ku-/Ka-band, IIP'98) + ACR (W-band) on NASA P-3*
  - ***TC4 Experiment 2007, APR-2 on NASA DC-8 + CRS (W-band) on NASA ER-2. (Shown in this slide)***
  - *TC4 2007 and GRIP 2010, APR-2 underflights of CloudSat.*



INSTRUMENTS	PROS	CONS	Readiness
ACR(W) + APR-2 (Ku/Ka, IIP'98) on DC-8 or P-3	• Safe/low cost, • Meets sensitivity • scanning	• Only clouds < 10km altitude • Large (two radars)	Ready, tested in 2003
CRS (W) + "H(iw)RAP" (Ku/Ka, IIP'04) on ER-2 (poss. GH)	• High-altitude • CRS well tested and meets sensitivity	• not scanning on ER-2 • Large (two radars) • Ka-band needs upgrades to achieve sens.	Planned readiness: Spring 2011
ACE Airborne Simulator (W/Ka/…) on GH or ER-2	• High-altitude, • scanning, • compact	• At concept level • Development costs	Submitted to IIP'10

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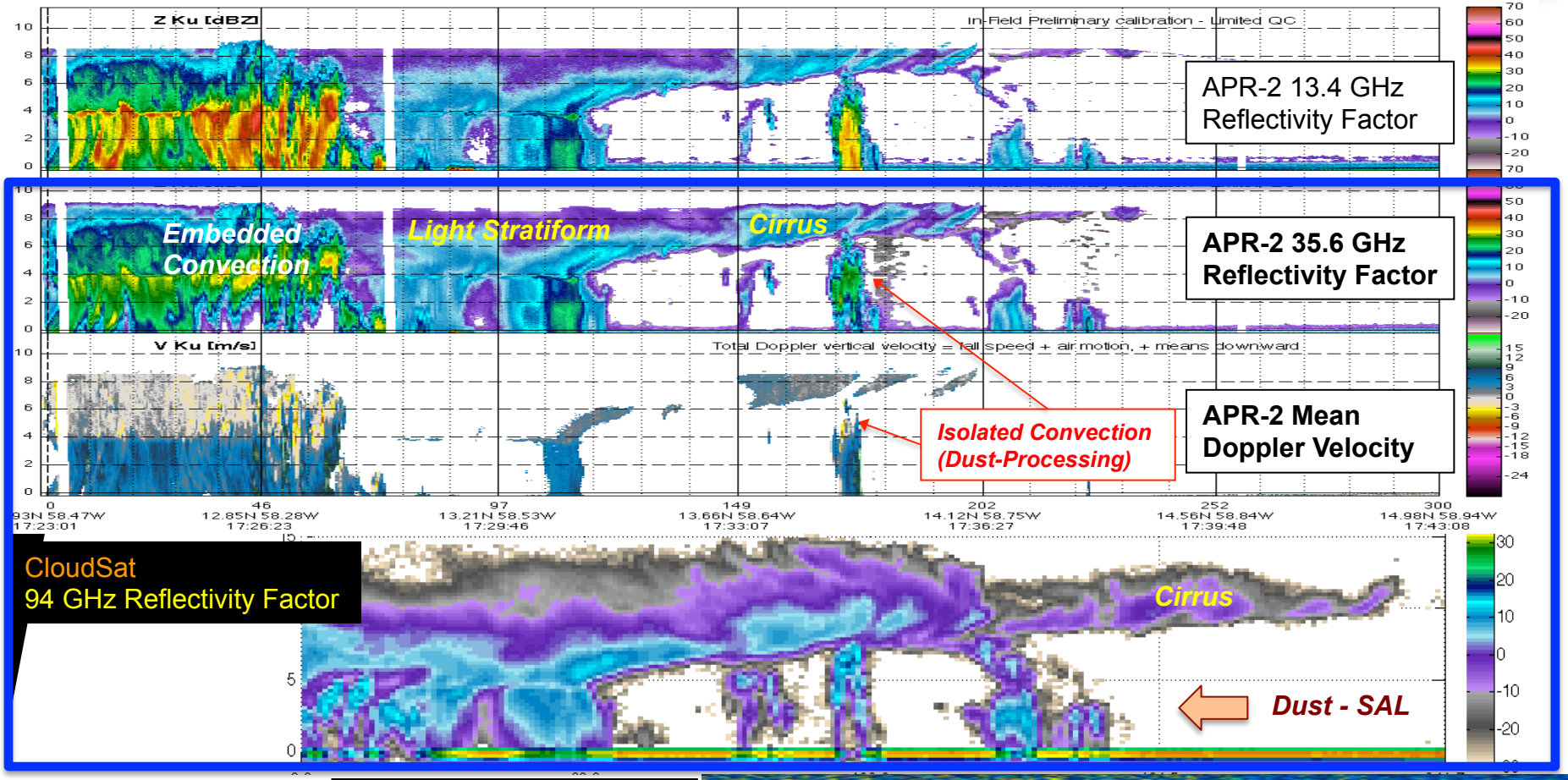
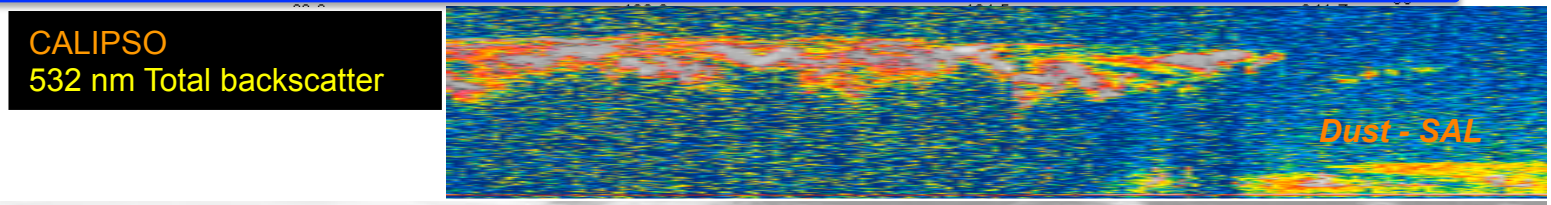
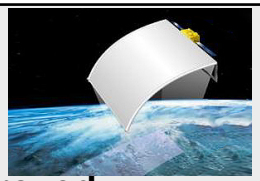
September 21, 2010
NASA GRIP – A-Train Underflight ~ 13.5N 58.5W





Recommended Path Forward

	Flight Segment	Ground Segment	Cal/Val
Necessary for baseline implementation	*-ACERAD Integrated Antenna System* *- ACERAD HPA: collaboration with SWOT* - Concept maturity, cost/risk assess./analyses.	*- ACE Radar retrieval algorithm tests* *- ACE Multi-instrum. algorithms*	*-Acquisition of W/Ka data + in situ samples* *-Analysis of existing datasets* **- Compact Airborne ACE radar**
Recommended to reduce mission cost/ risk	- ***Ka/W High Power Amplifier (mass, efficiency, lifetime)*** - **Advanced Pulse compression techniques**	*- Analysis of performance of advanced signal processing methods*	- Analysis of external active calibration facility
Recommended to improve performance margins & science	- **Phased Array ("PR-2 style") at Ka- and W-band.**  - **Ka-/W-band improved efficiency/packaging T/R MMIC** - **Ka/W-band reflectarray** - **Ka/W-band radiative structures** - *Lightweight Deployable Antennas*	*- Advanced retrieval algorithms (e.g., Data Assimilation based)*	**- 3+ frequency, Doppler, Polarimetric, Scanning, Advanced Airborne ACE radar** (relevant to NASA science beyond ACE)

Addressed in 2010 IIP proposals/SBIR calls, *planned for future ACT/AIST/ROSES.*